PMD and CD Sensitivity Enhancement in Directly Modulated Transmission Systems through RZ DM-DPSK

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Abstract: We compare PMD and CD tolerances of 10 Gb/s directly-modulated transmission formats, including directly-modulated RZ-DPSK, RZ-OOK and NRZ-OOK, using a 1.55 µm commercially-available DML. Along with an increased receiver sensitivity of 3 dB, we show experimentally that RZ DM-DPSK is more robust than directly-modulated RZ-OOK and NRZ-OOK to both PMD and CD.

Introduction

Transmission schemes employing directly modulated lasers have attracted increased attention in the past due to their intrinsic simplicity, low power consumption and cost-effectiveness, especially when applied to metro and access networks. The typical transmission distance of such networks (tens of kilometres), mostly comprised of single-mode fiber (SMF), makes direct modulation an attractive option for low-cost short-reach transmission [1]. However, directly modulated lasers (DML) experience a large amount of chirp, resulting in an increased spectral width, making them much less tolerant to both chromatic dispersion (CD) and first-order polarization-mode dispersion (PMD), referred to as differential group delay (DGD).

Previous work on directly modulated systems has focused on techniques to increase receiver sensitivity, extend reach [2], and increase robustness to CD and PMD. Techniques have included mid-span spectral inversion [3], electrical equalization [4, 5] and offset narrowband optical filtering [1].

In this paper we experimentally demonstrate a simultaneous increase in receiver sensitivity, along with increased tolerances to both CD and PMD in a 10 Gb/s directly modulated system by applying a modulating signal which induces a π phase shift for a 1-bit at the output of a commercially available 1.55 µm DML. We detect the signal using a Mach-Zehnder delay interferometer (MZI) followed by a balanced photodetector. This modulation technique has been demonstrated in the past [6, 7] and has been dubbed directly-modulated differential-phase-shift-keying (DM-DPSK). Along with an increased receiver sensitivity of ~3 dB, this format is approximately 3 dB more robust to PMD when compared to directly modulated RZ-OOK at 45 ps of DGD. It is also approximately 1.5 dB more robust than directly modulated NRZ-OOK and 2.5 dB more robust than directly modulated RZ-OOK at a CD value of 280 ps/nm.

Concept

Typical implementations of DPSK employ a CW laser followed by an external phase modulator [8]. It has also been shown in the past that DPSK signalling can be achieved through direct modulation of a distributed feedback (DFB) laser biased well above its threshold [6, 7]. As shown in Fig. 1, the modulating signal induces an instantaneous frequency shift of the optical signal. The resulting phase change is the integration of the frequency shift over the course of the bit period. By selecting a suitable drive signal it is possible to obtain the desired π phase shift out of the DML and therefore generate a DPSK signal via direct modulation. Assuming an ideal square pulse, in order to achieve a π phase shift it is necessary for the bit duration multiplied by the frequency shift to equal 0.5, as shown in equations (1) - (3). Therefore, if the pulse width is decreased the amplitude and therefore frequency shift must increase proportionately.

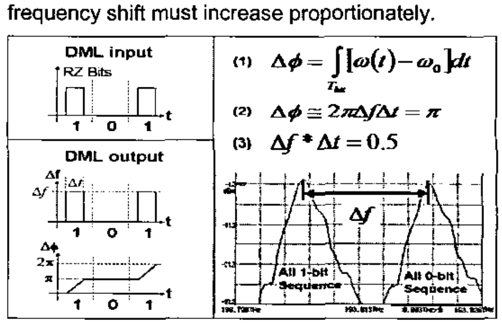

Fig. 1: Conceptual diagram of DM-DPSK

We obtain an appropriate drive signal through the use of an NRZ-to-RZ converter equipped with amplitude and pulse width tuning. Through fine tuning of both parameters we achieve the required π phase shift at the output of the DML. Our measured pulse width is around 55 ps for a 10 Gb/s data rate.

This modulation technique experiences the increased receiver sensitivity and increased robustness to PMD and CD, typical of DPSK formats, without the need for any external modulation. The increased sensitivity and robustness compared to traditional direct modulation schemes comes at the expense of a more complex receiver.

Experimental Setup

A simplified block diagram of our experimental setup to generate and receive RZ DM-DPSK and directly modulated RZ-OOK and NRZ-OOK in the presence of PMD and CD is shown in Fig. 2. The DML is biased at approximately 50 mA, compared to the laser threshold of 18 mA. The converter output can be switched to NRZ for NRZ-OOK by closing a switch to bypass the converter.

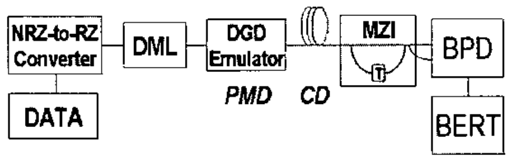

Fig. 2: Block diagram of directly modulated RZ-DPSK experimental setup for measurement of PMD sensitivity

Our receiver consists of a Mach-Zehnder delay interferometer followed by balanced photodetector and limiting amplifier. The detector data is sent to an error detector and BER is measured for varying amounts of PMD and CD.

To determine the impact of first-order PMD we use a commercially available PMD emulator [9]. DGD sensitivity is performed in a back-to-back configuration so that no CD is present. The impact of chromatic dispersion is investigated by using varying lengths of single-mode-fiber with a pre-determined CD of 17 ps/nm/km. Similarly, CD sensitivity is measured in the presence of zero DGD from the DGD emulator.

Results and Discussion

It is shown experimentally that directly modulated RZ-DPSK is more robust than directly modulated RZ-OOK in the presence of polarization PMD. Shown in Fig. 3 are the observed power penalties as a function of DGD in picoseconds. It has been extensively shown in the literature that RZ-OOK will outperform NRZ-OOK in the presence of DGD due to decreased energy leakage into adjacent bit slots [10].

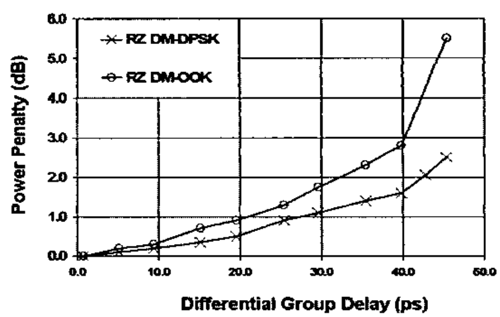

Fig. 3: First-order PMD (DGD) sensitivity of directly modulated RZ-OOK and RZ-DPSK

Directly modulated RZ-DPSK experienced approximately 3 dB less power penalty than directly modulated RZ-OOK in the presence of 45 ps of DGD. This increased tolerance is attributed to a decrease in inter-symbol interference as a result of delay demodulation at the receiver [11].

As shown in Fig. 4, RZ DM-DPSK is more robust to chromatic dispersion than both directly modulated RZ-OOK and NRZ-OOK. At a CD value of 280 ps/nm, an increased tolerance of 2.5 dB was observed when compared to RZ-OOK and 1.5 dB was observed when compared to NRZ-OOK. This increase in tolerance is a result of both a reduced spectral width and cancellation of noise terms in the balanced receiver [6]. It is also worth noting that NRZ-OOK is more robust to CD than RZ-OOK by approximately 1 dB at just above 280 ps/nm of CD. This decrease in tolerance to CD is expected because RZ-OOK occupies approximately twice the bandwidth of NRZ-OOK.

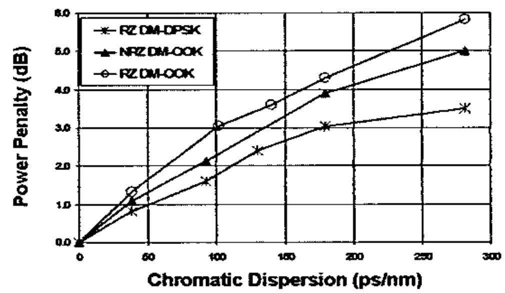

Fig. 4: Chromatic dispersion sensitivity of directly modulated transmission formats

Conclusions

In this paper we experimentally demonstrated that the robustness of a directly modulated link to PMD and CD can be increased by modifying the modulating drive signal to give a directly-modulated RZ-DPSK signal. An increase in robustness of 3 dB to PMD (of 45 ps) and 2 dB to CD (of 280 ps/nm) is obtained when compared to its directly modulated RZ-OOK counterpart. Furthermore, directly modulated RZ-DPSK is accompanied by an increased receiver sensitivity of approximately 3 dB, at the expense of a more complicated receiver.

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